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A method and system are provided for improving inter-beam connectivity in multiple spot beam satellite systems. The method and system employ, in the satellite transponder, independently switchable partitions of the transmission bandwidth of each received wideband channel. In the satellite transponder (100), partitions of equal and adjacent sub-channels are established, and an on-board switcher (60) which is employed with a common target intermediate frequency (IF) for all sub-channel cases and a bank of identical bandpass filters (50), routes transmissions appearing in one sub-channel on one beam's uplink into a sub-channel of a different beam's downlink, wherein the rerouted downlink sub-channel need not be the same sub-channel as the source uplink sub-channel. Specific embodiments independently operating local oscillators are provided for the frequency translation of the wideband uplink channel and the wideband downlink channel, allowing for unrestricted sub-channel beam switching. The capacity allocated between beam pairs can be accomplished without disrupting communication traffic on other non-involved beam pairs.

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## METHOD FOR IMPROVING INTER-BEAM CAPACITY SWITCHING FOR MULTIPLE SPOT BEAM SATELLITE SYSTEMS

### BACKGROUND OF THE INVENTION

The present invention relates to communication satellites and particularly to transponding satellites having a plurality of transmit and receive spot beams. More particularly, the invention is directed to a system using multi-beam communication satellites, each of which has spot beams that can be electrically interconnected to allow earth stations in the footprint of one spot beam to communicate with the earth stations in the footprint of other spot beams.

The term "spot beam" refers to a directional radiation pattern provided by a satellite antenna in which the area of geographic coverage is constrained to a terrestrial footprint and thus does not extend to all portions of the earth having a direct line of sight to the satellite. Such coverage patterns increase the power flux density received from and transmitted to the coverage area of interest, enabling communications between smaller, less powerful earth stations. In addition, such coverage patterns increase system capacity by enabling re-use of the transmission frequencies in each beam due to the collective spatial separation (directivity) of the beams.

In the field of geosynchronous communication satellites, the satellite communication band is typically divided into a number of wideband channels, each being supported by a separate transponder. Multi-beam communication satellites that offer inter-beam connectivity typically provide such connectivity only on a full channel-by-full channel (transponder-by-transponder) basis. However, in many applications the volume of communication traffic between two beams is not large enough to warrant the allocation of an entire wide-band channel. In such instances a portion of the allocated wide-band channel remains unused, and satellite

capacity is wasted. The situation can be partially remedied by partitioning the communications band into a larger number of narrower channels, with each channel again being supported by its own (narrow-band) transponder. However, such an  
5 alternative approach has the disadvantage of requiring a proportionately larger number of transponders and may result in prohibitively large satellite size, weight and power consumption requirements.

A further alternative technique overcomes some of  
10 the drawbacks of transponder-by-transponder beam interconnection through the use of on-board, sub-channel switching. One example is found in U.S. Patent No. 4,706,239 issued Nov. 10, 1987 to Ito et al. and assigned to KDD of Japan. With such a technique, the signals of a wide-band  
15 channel or channels contained in each beam are passed through filter banks which divide the channel spectrum into multiple sub-channels, each containing the signals from different, successively adjacent bands of the original (full-channel) spectrum. The sub-channels are then input to an on-board  
20 signal switching matrix which allows the sub-channels to be independently switched. Specifically, the technique allows the signals appearing in any given sub-channel of one uplink beam to be switched so that they appear in the corresponding (identical) sub-channel of a different downlink beam. This  
25 technique allows inter-beam capacity to be allocated with a finer increment without increasing the overall number of transponders.

The known sub-channel switching approach is limited, however, in that it provides switching only between directly-  
30 corresponding sub-bands in different beams. Thus, adjustment of the capacity allocated for beam-to-beam communication between a given set of beam pairs typically also requires sub-band adjustments that would disrupt communications in other beam pairs.

35 The problem can be illustrated by examining the following scenario. A satellite system includes four spot beams, each with an associated uplink and downlink. It is assumed that one wide-band channel (transponder) is used per

spot beam. Inter-beam connectivity is implemented on the satellite using the known sub-band switching approach, with each wide-band channel being divided into three sub-channels. For simplicity it is initially assumed that a transmission path is required from each beam's uplink to each of the other three beams downlinks, but not from any one beam's uplink to its own downlink. FIG.1A shows the initial inter-beam connectivity requirement and Fig. 1B shows an uplink and downlink sub-channel arrangement that satisfies this requirement. (The sub-channels of each wide-band channel are identified using the lower case letters a, b, and c. The numeral appearing in each sub-channel represents the sub-channel-associated uplink beam (1, 2, 3, or 4).)

Referring to Fig. 2A and 2B, assume that, at a subsequent time, traffic requirements make a different inter-beam connectivity desirable, and assume specifically that a transmission path is now required from the uplink of beam 1 to its own downlink; that twice the existing inter-beam capacity is required between beams 2 and 3; and that no inter-beam capacity is required from beam 1 to either beam 2 or beam 3. Assume also that there is to be no change in the inter-beam connectivities associated with beam 4. FIG. 2A illustrates the new inter-beam connectivity requirement and Fig. 2B shows the uplink and downlink sub-channel arrangement that satisfies this requirement. In the prior art technique, sub-channels appearing in one beam may only be switched to the directly corresponding sub-channels in another beam. That is, signals appearing in sub-channel "a" of beam 1's uplink can be switched to a corresponding sub-channel "a" in beams 1, 2, 3 or 4's downlink, but not to any sub-channel "b" of any beam's downlink. (In the downlink sub-channel arrangement of FIG. 2B, the circles indicate the sub-channels that must be switched in order to achieve the desired new connectivity.)

To maintain the connectivity between beam 4 and each of the other beams, the switching restrictions associated with the prior art technique required that the sub-channels on which beam 4 connects with beams 2 and 3 be changed, resulting

in the disruption of all on-going traffic between beam 4 and beams 2 and 3.

In many multi-beam satellite applications, including telecommunication applications, inter-beam traffic requirements may vary significantly according to traffic load on the day of the week, or even the time of day. Likewise, the traffic pattern exhibited between a given beam pair may or may not be similar to that exhibited between a different beam pair. The ability to easily change the inter-beam capacity available between selected beam pairs without impacting traffic on other beam pairs is therefore highly desirable in these applications.

A technique for creating inter-beam connectivity that allows flexible adjustment of inter-beam capacity without requiring a large number of narrow-band transponders, and without the potential for traffic disruption displayed by the previously disclosed sub-channel technique, would represent a significant improvement.

#### SUMMARY OF THE INVENTION

According to the invention, a method and system are provided for improving inter-beam connectivity in multiple spot beam satellite systems. The method and system employ, in the satellite transponder, independently switchable partitions of the transmission bandwidth of each received wideband channel. In the satellite transponder, partitions of equal and adjacent sub-channels are established, and an on-board switcher is employed with a common target intermediate frequency (IF) for all sub-channel cases, together with a bank of identical bandpass filters. The switcher selectively routes transmissions appearing in one sub-channel on one beam's uplink into a sub-channel of a different beam's downlink, wherein the rerouted downlink sub-channel need not be the same sub-channel as the source uplink sub-channel.

In a specific embodiment of the invention, an uplink wideband receiver receives a beam signal and provides a plurality of wideband channel signals separated in frequency, then provides each wideband channel to a plurality of first

mixers driven by a series of first local oscillators, each of which in turn provides individual frequency translation of the individual uplink sub-channels to an intermediate frequency which is common to all wideband channels and common to all sub-channels. Thus, a switcher can then freely reroute any uplink sub-channel to any downlink sub-channel. A second set of local oscillators drive a second set of mixers for each downlink sub-channel for each wideband channel. The second local oscillators are independently tunable from each other and are selectively tuned to compliment a selected first local oscillator in order to reconstruct the spectrum of each wideband downlink channel by the frequency translation of the sets of downlink sub-channels. All wideband downlink channels have exactly the same number and spectral allocation of sub-channels as the wideband uplink channels.

The inventive configuration and method allow flexible switching and adjustment of the capacity available within each beam for beam-to-beam communication. The invention represents an improvement on previously disclosed techniques in that it places no restrictions on the relative spectral position of the re-allocated beam-to-beam capacity. The elimination of such restrictions permits the capacity available between given beam pairs to be adjusted without disrupting on-going services in other beam pairs, allows more efficient use of the available satellite capacity, and simplifies the processing required to plan beam-to-beam connections.

While prior art transmission bandwidth allocation techniques for each received wide-band channel (transponder) contained within each spot beam uplink permitted partitioning on the satellite into a number of sub-channels, the present invention achieves true flexible inter-beam connectivity by relocating the transmissions appearing in a given sub-channel of one beam's uplink to a sub-channel of a different beam's downlink through the use of an on-board switching function. It is a significant feature of the present invention that the destination downlink sub-channel need not be the same as the source uplink sub-channel. This object may be achieved using

radio frequency (RF) translation, filtering, and switching techniques.

The invention will be better understood upon reference to the following detailed description in connection with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A and 1B illustrate a conventional frequency allocation and channel pattern permitted by the prior art techniques.

Fig. 2A and 2B illustrate a further conventional frequency allocation and channel pattern permitted by the prior art techniques.

Fig. 3A and 3B illustrate a frequency allocation and channel pattern according to the invention in a four-beam, three sub-channel network node.

Fig. 4 is an illustration of a specific embodiment of the invention implemented in an orbiting satellite.

#### DESCRIPTION OF SPECIFIC EMBODIMENTS

FIG. 3A and 3B provide an illustration of the invention using a four beam, three sub-channel network scenario. In this scenario, the desired initial beam-to-beam connectivity, and the initial uplink and downlink sub-channel configurations implementing this connectivity, are assumed to be as shown in FIG. 1A and 1B. The modified inter-beam connectivity desired is shown in FIG. 3A. This connectivity, if unchangeable, is identical to that of known sub-channel switching systems with all the shortcomings of the known sub-channel switching technique (see FIG. 2B). FIG. 3B shows the uplink sub-channel configuration for each beam according to the invention with a corresponding downlink sub-channel configuration made possible by the sub-channel switching flexibility of the present invention. The downlink sub-channels that have been relocated by for example link independent RF1-IF-RF2 frequency translation to achieve the desired connectivity are indicated in FIG. 3A, the circles indicating the noted changes. Note that the improved



technique allows the desired connectivity changes involving beams 1, 2, and 3 to be implemented without disrupting any on-going traffic entering or leaving the non-involved beam (beam 4).

5           FIG. 4 shows a transponder set 100 employing a sub-channel switching system operative according to the inventive technique. In this embodiment the number of uplink and downlink spot beams employed by the satellite system is  $N$  (an integer greater than 1), and the total number of wideband  
10 channels within the system's spot beams is  $M$  (an integer greater than or equal to  $N$ ). Each wideband channel is supported by a separate transponder. A receive antenna 10, of which there is one per uplink beam is coupled to a receiver 20 that amplifies and frequency downconverts the received  
15 spectrum to a lower intermediate frequency (IF). A demultiplexing element 30 separates the wideband channels contained within the associated beam. The output of each wideband channel is provided to a splitter 32.

          A set of  $L$  frequency conversion elements 40  
20 translate the received wideband channel spectrum to a second intermediate frequency (IF) spectrum. The frequency of the signal of each of the local oscillators (LO) therein is independently used in each downconversion function, the frequency being selected such that different, preferably  
25 successively adjacent portions of the wideband signal, each separated in frequency by  $1/L$ th of the wide-band channel bandwidth, are translated to a common IF center frequency,  $F(C)$ . Band pass filters 50, each having a center frequency  $F(C)$  and a nominal bandwidth of to  $1/L$ th of the wide-band  
30 channel bandwidth receive the output of a corresponding mixer 44. Each of the  $L$  downconverted spectra is passed through such a filter to create  $L$  separate sub-channels, each centered at the IF frequency  $F(C)$ . A  $P \times P$  switch matrix 60, with  $P$  equal to the product of  $L$  and  $M$ , is used for controllably  
35 routing signals within the passband. In this embodiment, the  $P \times P$  switch matrix allows each of the  $P$  uplink sub-channels to be switched to any of the  $P$  downlink sub-channels. The path positions of the individual  $P \times P$  switching elements are

typically under microprocessor control programmed in a straightforward manner which are configurable via telemetry signaling transmitted from a ground-based satellite control facility.

5           The L frequency conversion elements 70 translate the L sub-channels associated with a particular wide-band downlink channel to their assigned, successively adjacent positions in that wide-band channel's downlink spectrum. Downlink  
10           multiplexing element (combiner) 80 with associated filters 74 to eliminate undesired product image signals combines each of the signals of the wideband channels associated with a particular downlink spot beam, thus constructing the signal content for an individual transponder or wideband downlink  
15           channel. The output of each combiner 80 is routed to an r.f. amplifier (the downlink transponder amplifier) 84, the output of which is combined with the outputs of other transponder amplifiers in a multiplexer 86. Finally, a directional  
20           downlink antenna 90, of which there is one per downlink beam and which corresponds to an associated uplink beam 10, receives the combined transponder (downlink wideband channel) signals and completes the wireless link back to the ground.

          One of the advantages of this unrestricted uplink and downlink channel switching technique is the ability to adjust the capacity allocated between beam pairs without  
25           disrupting communication traffic on other non-involved beam pairs, thus flexibly allocating and adjusting the amount of satellite capacity provided for beam-to-beam communications. Other advantages will be evident.

          The invention has been explained with reference to  
30           specific embodiments. Other embodiments will be apparent to those of ordinary skill in the art. It is therefore not intended that this invention be limited, except as indicated by the appended claims.

WHAT IS CLAIMED IS:

1           1.    In a multiple spot-beam satellite communication  
2    system, a method for inter-beam switching comprising the  
3    steps, in a communication relay system in a satellite, of:  
4            receiving uplink beams via a plurality of uplink  
5    beam subsystems;

6            for each uplink beam, translating each subchannel  
7    signal of said uplink beam with a first independent local  
8    oscillator specific to its subchannel to produce an  
9    intermediate frequency-translated subchannel signal in an  
10   intermediate frequency which is common for said communication  
11   relay system;

12           rerouting through a switching network each said  
13   intermediate-frequency modulated subchannel signal to a  
14   desired downlink beam subsystem; and

15           translating each rerouted intermediate-frequency  
16   modulated subchannel signal to a desired downlink subchannel  
17   frequency with a second independent local oscillator specific  
18   to its subchannel to produce a downlink subchannel signal in  
19   any desired subchannel and any desired downlink beam.

1           2.    In a multiple spot-beam satellite communication  
2    system, an apparatus for inter-beam switching comprising the  
3    steps, in a communication relay system in a satellite, of:

4            a plurality of uplink beam subsystems for receiving  
5    uplink beams;

6            for each uplink beam, means for translating each  
7    subchannel signal of said uplink beam with a first independent  
8    local oscillator specific to its subchannel to produce an  
9    intermediate frequency-translated subchannel signal in an  
10   intermediate frequency which is common for said communication  
11   relay system;

12           a switching network for rerouting each said  
13   intermediate-frequency modulated subchannel signal to a  
14   desired downlink beam subsystem; and

15           means for translating each rerouted intermediate-  
16   frequency modulated subchannel signal to a desired downlink

17 subchannel frequency with a second independent local  
18 oscillator specific to its subchannel to produce a downlink  
19 subchannel signal in any desired subchannel and any desired  
20 downlink beam.

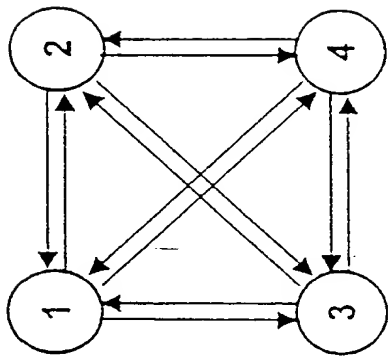
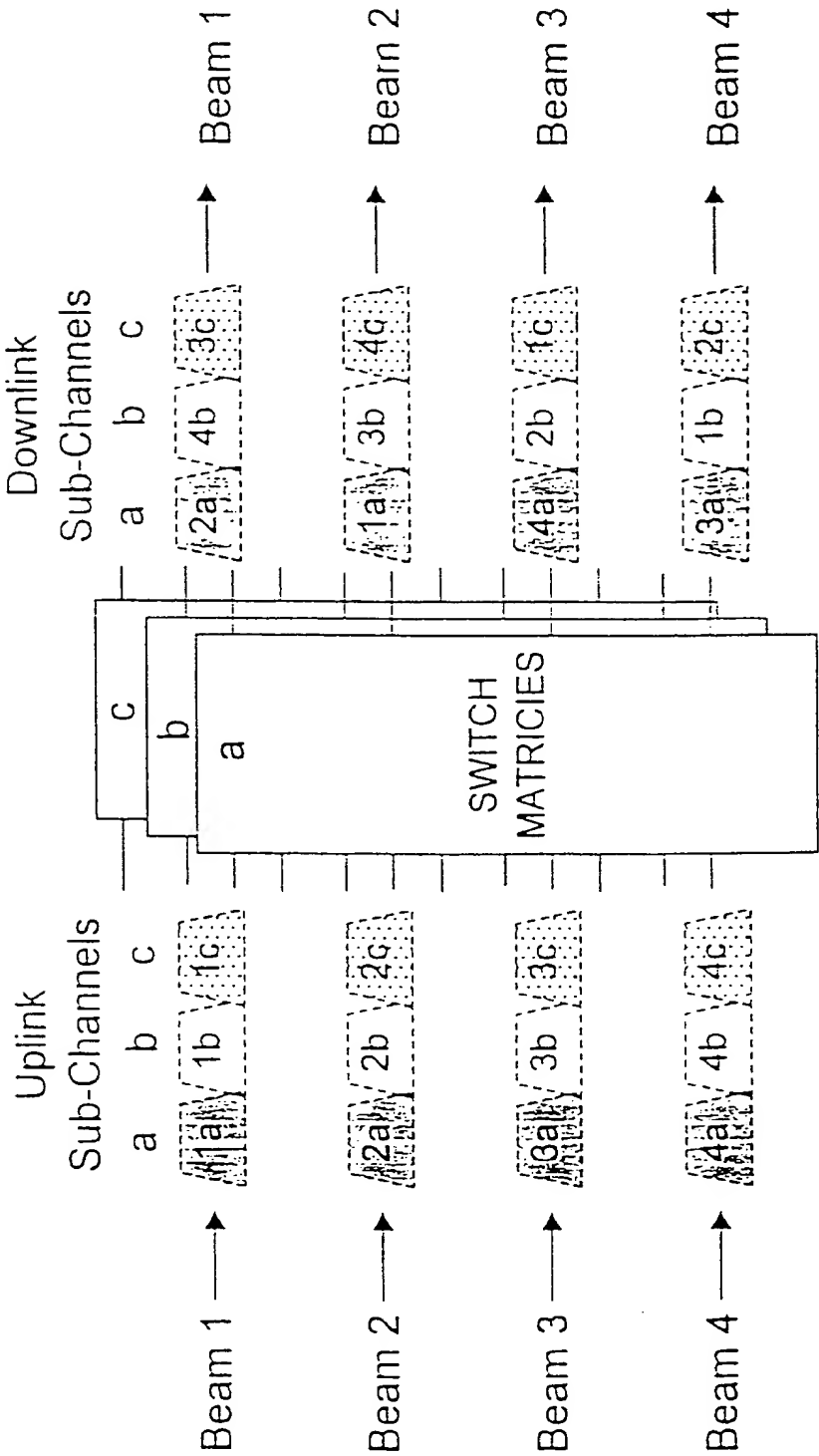
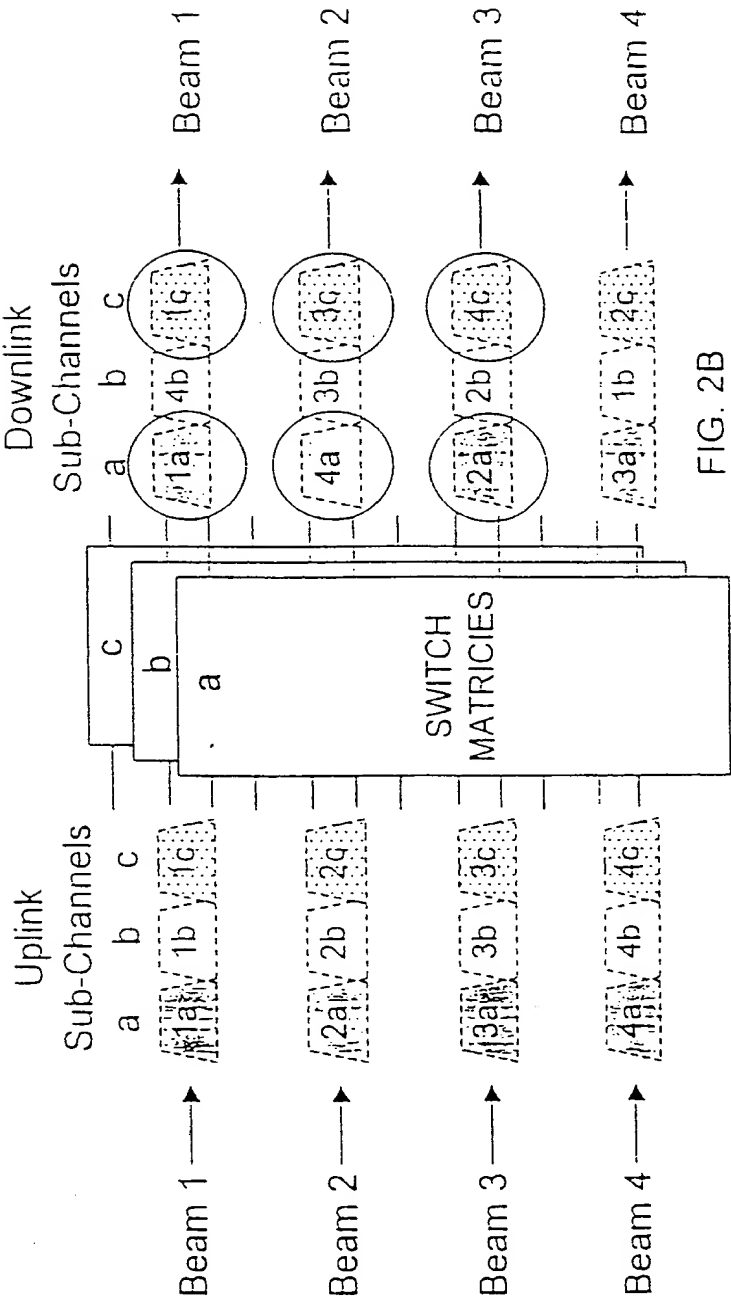
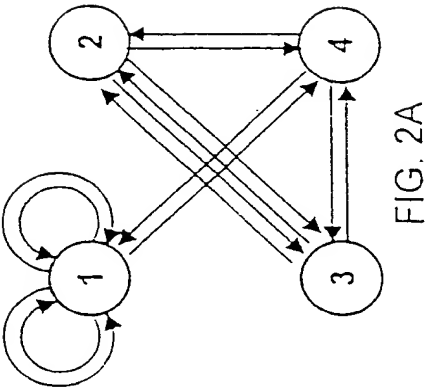


FIG. 1A





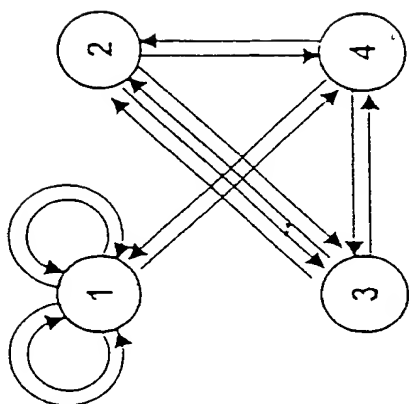


FIG. 3A

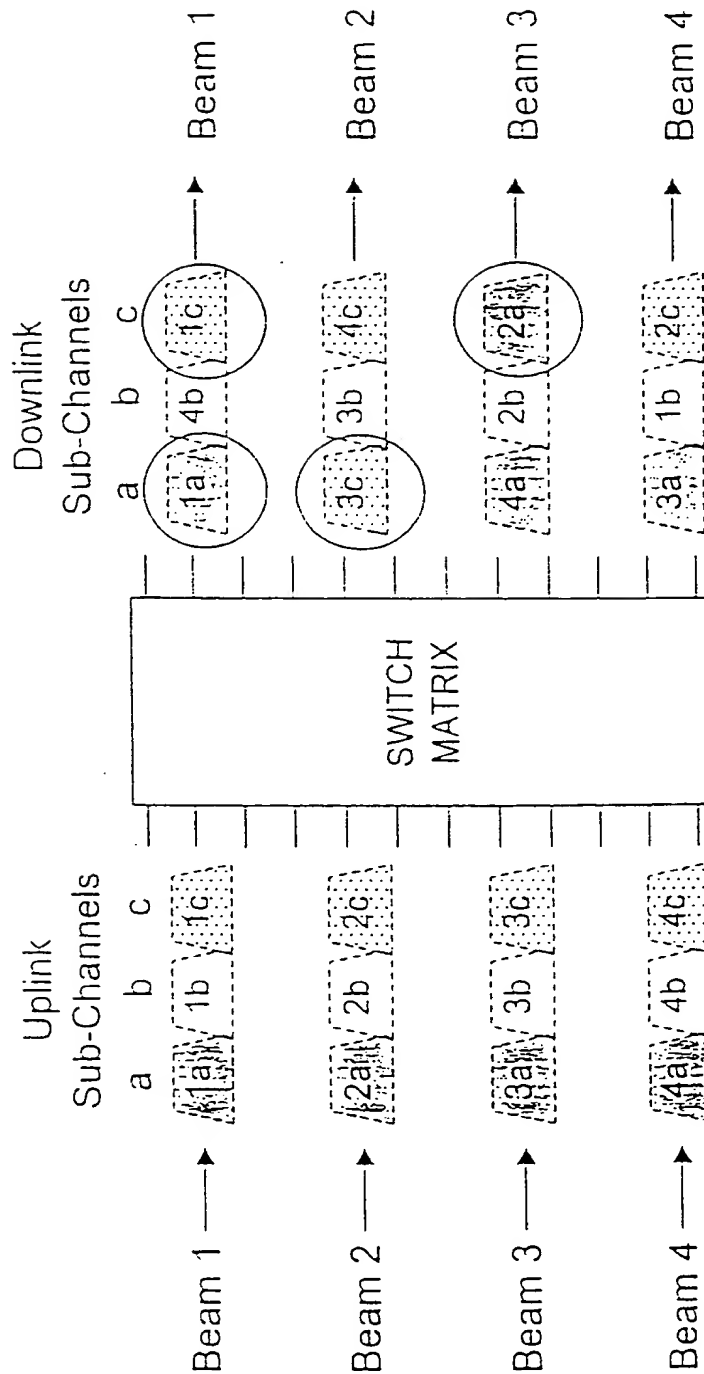
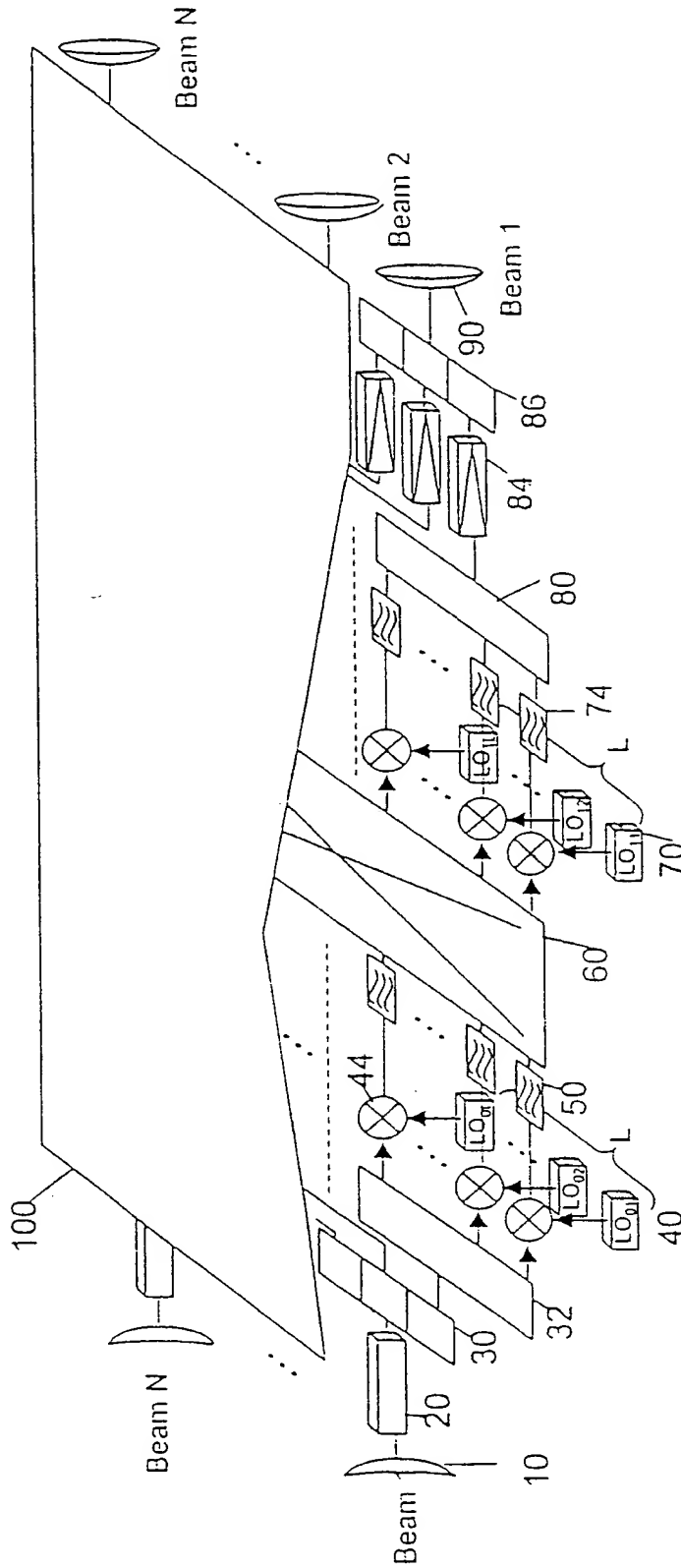


FIG. 3B

FIGURE 4





## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US99/00828

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 7/185

US CL : 370/316, 315; 455/12.1

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 370/316, 315, 310, 317, 318; 455/12.1, 11.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No. |
|-----------|--|-----------------------|
| Y,P       | US 5,822,312 A (PEACH ET AL) 13 October 1998, Figs. 3a-3b columns 1-2 lines 1-67, column 4 lines 45-67, column 5 lines 1-53.                                 | 1-2                   |
| Y,P       | US 5,825,325 A (O'DONOVAN ET AL) 20 October 1998, Figs 1, 2A and 2B, columns 1-2 lines 1-67, column 3 lines 1-47, column 4 lines 37-67, column 5 lines 1-54. | 1-2                   |



Further documents are listed in the continuation of Box C.



See patent family annex.

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